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WELDER-LMP: A FAST-TRANSIENT, THREE DIMENSIONAL COMPUTATIONAL MODEL FOR CONTINUOUS AND PULSED HIGH-ENERGY-DENSITY WELDING PROCESSES

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ABSTRACT

A discrete element computational model containing the pertinent physics associated with the three phase processes inherent in deep penetration (keyhole) welding of metals and alloys has been developed and used to conduct preliminary computational experiments on pulsed laser welding. The results will be compared to physical results obtained on Inconel 718 using a high power CO_2 (10.6 μm wavelength) laser at The University of Tennessee Space Institute. This paper highlights the computer model and its basic attributes relative to prediction of real time occurrences within the weld pool and surroundings for laser keyhole welding.

The following provides a brief outline of the capabilities of the WELDER-LWP Code and describes the conditions for which it is applicable.

Simulation Capabilities:

o Considers the time-accurate, fast-transient, three-dimensional (or axisymmetric) convection, which can predict the development of the "weld-cavity", throughout the continuous or pulsed high-energy-density laser-beam or e-beam welding process.

Constitution of the three (3)-Phase [solid-liquid-gas (vapor)] Metal:

o Considers the metal as an "alloy-metal", in general, (a) consisting of different "constituent-metals", for studying meso/macro-scale segregation problems, based on "Constituent-fractions", or (b) consisting of a single-constituent metal;

o Considers two (2) "states", as "solid-state and phase)" and "fluid-state (multi-phase)", associated with (a) each constituent-metal, and the alloy-metal, for studying meso/macro-scale segregation problems, based on "state-fractions", or (b) the alloy-metal as a single-constituent metal;

o Considers two (2) "phases", as (a) "liquid-fluid-phase" and (b) "gas (vapor)-fluid-phase" of the fluid-state (multi-phase), associated with (a) each constituent-metal, and the alloy metal, for studying meso/macro-scale segregation problems, based on "phase-fractions", or (b) the alloy-metal as a single-constituent metal.

Phase-transformation Conditions:

o Considers "non-equilibria (kinetic)", as required for high-temperature-elevation-rate conditions, or "pseudo-equilibria (static)" "solidification-liquification phase-transformation", (a) for each constituent-metal, and the alloy-metal, metal, for studying meso/macro-scale segregation problems, based on state-fractions and constituent-fractions, or (b) for the alloy-metal as a single-constituent metal;

o Considers "non-equilibria (kinetic)", as required for high-temperature-elevation-rate conditions, or "pseudo-equilibria (static)" "condensation-evaporation phase-transformation", (a) for each constituent-metal, and the alloy-metal, metal, for studying meso/macro-scale segregation problems, based on phase-fractions and constituent-fractions, or (b) for the alloy-metal as a single-constituent metal.

Thermophysical and transport properties of the metal:

o Considers temperature-dependent "thermophysical and transport properties" for the solid-state (and phase) and the two (2) phases, as the

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liquid-fluid-phase and the gas (vapor)-fluid-phase, of the fluid-state (multi-phase), associated with (a) each constituent metal, and the alloy-metal, for studying meso/macro-scale segregation problems, based on constituent-fractions, state-fractions and phase-fractions, or (b) the alloy-metal as a single-constituent metal.

Surface conditions on the weld-cavity:

o Considers physically realistic, "flex-surface" (deformable, elasto-plastic) conditions, for the surface of the weld-cavity, which incorporate, individually, and explicitly, (a) the surface-tension pressure, and (b) surface-tension-shear (Marangoni) stress;

o Considers physically realistic, temperature-dependent "surface-tension-coefficient" and surface-tension-rate-coefficient", which control the surface-tension-pressure and surface-tension-shear (Marangoni) stress effects, (a) for the liquid-fluid-phase of each constituent metal, and the alloy-metal, or (b) for the alloy-metal as a single-metal;

o Considers physically realistic, "vapor-venting" conditions from the surface of the weld-cavity, (a) for each constituent-metal, as segregated evaporation, associated with more volatile constituent-metals, for studying meso/macro-scale segregation problems, based on phase-fractions and constituent-fractions, or (b) for the alloy-metal as a single-constituent metal.

High-energy-density, laser-beam or e-beam heating conditions:

o Considers, accurately, the specified geometrical details of the "footprint", as (a) mode-00 (Gaussian), (b) mode-10 (two-peak) and (3) square (top-hat), for determining the "energy-deposition flux" on the surface of the weld-cavity;

o Considers, realistically specified, "absorbtivity factors", based on the solid-state, liquid-fluid-phase or gas (vapor)-phase of the alloy-metal, for determining the energy-absorption flux" through the surface of the weld-cavity;

o Considers optically transparent characteristics of the gas (vapor)-phase of the alloy-metal, which allows (a) for the penetration, (completely or partially) of the high-energy-density, laser-beam or e-beam, through the surface, and through the vapor-core, and consequently, (b) for the controlling heating conditions to occur at the liquid-gas (vapor) interface, enclosing the vapor-core in the weld-cavity, within the footprint;

o Considers, accurately, the specified fast-transient energy-deposition conditions, associated with tailored-pulse or pseudo-continuous (with high-frequency variations) operational conditions of the high-energy-density laser-beam or e-beam.

Environmental conditions on the workpiece:

o Considers, explicitly, specified environmental-pressure conditions on the weld-cavity, which allows for simulations of the welding process, under the space conditions and with special-atmosphere conditions over the workpiece;

o Considers modeled, approximately but realistically, free-convection-cooling conditions, from the surface of the weld-cavity and from the surface of the workpiece, throughout the welding process, including the cooling period;

o Considers, approximately but realistically, the effects of the shielding-gas-flow conditions, including (a) the stagnation-pressure variation on the surface of the weld-cavity, (b) shear-stress, induced by the flow on the surface of the weld-cavity, and (b) forced-convection-cooling conditions, from the surface of the weld-cavity and the surface of the workpiece;

o Considers, approximately, surface-plasma-formation effects, over the surface of the weld-cavity, which can alter the footprint of the high-energy-density laser-beam or e-beam.

A detailed report on the WELDER-LMP Code is in preparation and should be available early in 1993.